

# Improved Bipolar Junction Transistor

## FIELD OF THE INVENTION

The present invention relates to improved bipolar  
5 junction transistor. In particular the breakdown voltage of  
the collector-base junction is improved while maintaining a  
high cutoff frequency and improving the maximum operating  
frequency.

## BACKGROUND OF THE INVENTION

Shown in Figure 1 is an integrated circuit bipolar  
junction transistor (BJT). In general a heavily doped  
buried layer 20 is formed in a silicon substrate 10 and  
will form the collector contact region of the transistor.  
15 An epitaxial layer 30 is then formed on the substrate 10  
and the buried layer 20 to form the lightly doped or  
intrinsic collector region. Two diffusions 40 and 50 are  
formed in the epitaxial layer 30 to form the base region 40  
and the emitter region 50 of the BJT. For a NPN BJT the  
20 substrate will be p-type. The buried layer 20 will be doped  
n+, the epitaxial layer will be lightly doped n-type, the  
first diffusion region 40 will be p-type, and the second  
diffusion region 50 will be doped n+. For a PNP BJT the  
substrate will n-type. The buried layer 20 will be doped



For a high cutoff frequency, the collector resistance and the collector-base space charge layer must be optimized for a given base width  $W_B$  and emitter-base doping profile.

In the instant invention it will be assumed that the

5 emitter-base doping profile is fixed. Therefore, it is the collector doping profile which is changed to optimize the transistor performance for improving the breakdown voltage of the common-emitter configuration ( $BV_{CEO}$ ) and the ratio of the cutoff frequency to the maximum frequency ( $f_t/f_{max}$ )  
10 for a given technology. Previously, tradeoffs had to be made in optimizing both  $BV_{CEO}$  and  $f_t/f_{max}$ . These tradeoffs involved the collector width  $W_C$  and the collector doping levels. An optimum BJT will maximize both  $BV_{CEO}$  and  $f_t/f_{max}$ . Such optimization and maximization is not possible  
15 under current design methodology. There is therefore a need for an improved BJT that simultaneously maximizes both  $BV_{CEO}$  and  $f_t/f_{max}$  for optimum performance.

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BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, wherein like reference numerals represent like features, in which:

FIGURE 1 is a cross-section diagram of a convention BJT.

FIGURE 2 is a cross-section diagram showing the collector region of a BJT according to an embodiment of the instant invention.

Figures 3-5 are simulated curves showing the improvements obtained in BJT performance form an embodiment of the instant invention.

1951/52	1952/53	1953/54	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60	1960/61	1961/62	1962/63	1963/64	1964/65	1965/66	1966/67	1967/68	1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034/35	2035/36	2036/37	2037/38	2038/39	2039/40	2040/41	2041/42	2042/43	2043/44	2044/45	2045/46	2046/47	2047/48	2048/49	2049/50	2050/51	2051/52	2052/53	2053/54	2054/55	2055/56	2056/57	2057/58	2058/59	2059/60	2060/61	2061/62	2062/63	2063/64	2064/65	2065/66	2066/67	2067/68	2068/69	2069/70	2070/71	2071/72	2072/73	2073/74	2074/75	2075/76	2076/77	2077/78	2078/79	2079/80	2080/81	2081/82	2082/83	2083/84	2084/85	2085/86	2086/87	2087/88	2088/89	2089/90	2090/91	2091/92	2092/93	2093/94	2094/95	2095/96	2096/97	2097/98	2098/99	2099/00	2100/01	2101/02	2102/03	2103/04	2104/05	2105/06	2106/07	2107/08	2108/09	2109/10	2110/11	2111/12	2112/13	2113/14	2114/15	2115/16	2116/17	2117/18	2118/19	2119/20	2120/21	2121/22	2122/23	2123/24	2124/25	2125/26	2126/27	2127/28	2128/29	2129/30	2130/31	2131/32	2132/33	2133/34	2134/35	2135/36	2136/37	2137/38	2138/39	2139/40	2140/41	2141/42	2142/43	2143/44	2144/45	2145/46	2146/47	2147/48	2148/49	2149/50	2150/51	2151/52	2152/53	2153/54	2154/55	2155/56	2156/57	2157/58	2158/59	2159/60	2160/61	2161/62	2162/63	2163/64	2164/65	2165/66	2166/67	2167/68	2168/69	2169/70	2170/71	2171/72	2172/73	2173/74	2174/75	2175/76	2176/77	2177/78	2178/79	2179/80	2180/81	2181/82	2182/83	2183/84	2184/85	2185/86	2186/87	2187/88	2188/89	2189/90	2190/91	2191/92	2192/93	2193/94	2194/95	2195/96	2196/97	2197/98	2198/99	2199/00	2200/01	2201/02	2202/03	2203/04	2204/05	2205/06	2206/07	2207/08	2208/09	2209/10	2210/11	2211/12	2212/13	2213/14	2214/15	2215/16	2216/17	2217/18	2218/19	2219/20	2220/21	2221/22	2222/23	2223/24	2224/25	2225/26	2226/27	2227/28	2228/29	2229/30	2230/31	2231/32	2232/33	2233/34	2234/35	2235/36	2236/37	2237/38	2238/39	2239/40	2240/41	2241/42	2242/43	2243/44	2244/45	2245/46	2246/47	2247/48	2248/49	2249/50	2250/51	2251/52	2252/53	2253/54	2254/55	2255/56	2256/57	2257/58	2258/59	2259/60	2260/61	2261/62	2262/63	2263/64	2264/65	
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The NPN or PNP bipolar transistor will have a deep buried layer 20 with a high doping concentration so that the collector resistance is minimized. The region of the collector where most of the current flow occurs 80 will have a high concentration of scattering centers. The required concentration of scattering centers will be greater than about  $0.5 \times 10^{18} \text{ cm}^{-3}$  for silicon and silicon germanium epitaxial layers 100. In an embodiment of the instant invention these scattering centers can be introduced by counterdoping the collector region. The required concentration of free carriers in the collector region is dependent on the particular transistor application. For the case where the required free carrier concentration is  $n$ , then the following relation between the required numbers of donor atoms ( $N_D$ ) and acceptor atoms ( $N_A$ ) holds:

$$n = N_D - N_A \quad (1)$$

where, because of the requirement for the minimum number of scattering centers that must be present,  $N_A$  must be greater than  $0.5 \times 10^{18} \text{ cm}^{-3}$ . The value of  $N_D$  is therefore

20 given by:

$$N_D > n + 0.5 \times 10^{18} \quad (2).$$

Equation (2) is valid for the case of a NPN transistor. For the case of a PNP transistor a similar relationship holds

for the required acceptor concentration given that the required hole concentration in the collector region is  $p$ . This relationship is given by:

$$N_A > p + 0.5 \times 10^{18} \quad (3)$$

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For the case of silicon and silicon germanium layers 100 the acceptor atoms can be selected from the group consisting boron, aluminum, gallium, indium, and carbon. The donor atoms can be selected from the group consisting  
10 of phosphorous, arsenic and antimony. The donor and acceptor atoms can be incorporated into the epitaxial layer 100 during growth or can be introduced by thermal diffusion or ion implantation. In another embodiment of the instant invention, the scattering centers could be formed by the  
15 introduction of neutral scattering centers. Here, as in the previous case, the concentration of these neutral scattering centers should be greater than  $0.5 \times 10^{18} \text{ cm}^{-3}$ . As stated above the introduction of scattering centers in the collector region 80 results in an increase in the breakdown  
20 voltage  $BV_{ceo}$ .

In general as the electric field in semiconductor increases the velocity of the electrons and holes increases. This relationship is fairly linear over low and



moderate electric fields. For high electric fields  
(typically  $> \sim 10^5$  V/cm) the velocity of electrons and holes  
saturates at about  $10^7$  cm/s. For electric fields higher than  
that required for velocity saturation the mobility of the  
5 electrons and holes is independent of doping concentration.  
Therefore as long as the electric field is high enough to  
cause velocity saturation, increasing the dopant  
concentration will not affect the transistor performance.  
In the case of the instant invention, these velocity  
10 saturation effects impose additional constraints on the  
instant invention. The width of the collector region  $W_{CD}$  90  
shown in Figure 2 must be such that under normal operating  
conditions the depletion region width in the collector  
region  $W_{depcol}$  must be greater than  $W_{CD}$ . Stated differently,  
15 the region in the collector between the collector buried  
layer 20 and the edge of the base region 40 must be fully  
depleted during normal operation (i.e. with the collector-  
base junction reversed biased). Given the improvement in  
breakdown voltage  $BV_{ceo}$  achieved by the inclusion of  
20 scattering centers, this requirement of high collector  
fields and full depletion can easily be achieved by  
reducing the width  $W_{CD}$  90. Reducing the width  $W_{CD}$  will lead  
to an improvement in the ratio of  $F_t/F_{max}$ . Until recently,  
creating a uniform counterdoped layer was extremely

difficult without excessive diffusion. As vertical dimensions are being scaled however, the vertical dimensions that new high performance devices are approaching make the use of this idea more manufacturable.

- 5 Counterdoping using ion-implantation over a 1000 to 1500 Angstrom region is possible to the accuracy required for the instant invention. The value of  $W_{CD}$  should therefore be less than about 1500 Angstrom.

- 10 Previous BJT designs increase the buried layer distance to the base to increase the breakdown voltage  $BV_{ceo}$ . They also increase the doping concentration in the collector to try to reduce the onset of the Kirk effect for this wider collector region. This leads to an impossible balance in
- 15 the collector design to minimize collector resistance, while maintaining a high breakdown voltage. The instant invention offers the following advantages: a) improved breakdown voltage for a given collector geometry; b) improved  $F_t$  performance for a given breakdown voltage; c)
- 20 an added variable for the design of high performance bipolar transistors; d) delays the onset of the Kirk effect by allowing very narrow collectors for a given  $BV_{ceo}$ ; and e) improves the maximum  $BV_{ceo} * F_t$  for a given narrow collector bipolar transistor.

As an example of the device improvements possible using the instant invention, consider the following PNP bipolar transistor simulation where a comparison of device

5 performance with and without the narrow counter doped collector of the instant invention is illustrated in Figures 3 - 5. The simulation was carried out using the standard device simulator Avante' Medici. In Figure 3, a typical PNP transistor doping profile for a SiGe base  
10 transistor is shown. The emitter 140, base 130 and buried collector layer 110 are kept constant in all comparisons. The only variable is the collector 120 doping concentration and the collector width. The doping profile for the collector has a p-type active doping concentration of  $3 \times 10^{16}$   
15  $\text{cm}^{-3}$ . For the counterdoped example, the actual doping in the collector is  $9.7 \times 10^{17} \text{cm}^{-3}$  of n-type dopant, with  $1.0 \times 10^{18} \text{cm}^{-3}$  of p-type dopant. For the non-counterdoped results, the collector is doped to  $3 \times 10^{16} \text{cm}^{-3}$ .

20 Shown in Figures 4(a) and 4(b) are the breakdown voltage curves obtained for the non-counterdoped and counterdoped devices. In the normal non-counterdoped collector shown in Figure 4(a), the breakdown voltage is close to 6 volts 120, whereas for the counterdoped



reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

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